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Adam et al.

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(54) **METHOD OF FABRICATING A SEMICONDUCTOR DEVICE INCLUDING EMBEDDED CRYSTALLINE BACK-GATE BIAS PLANES**

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(51) **Int. Cl.**

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H01L 21/84 (2006.01)
H01L 29/786 (2006.01)
H01L 27/12 (2006.01)

(52) **U.S. Cl.**

CPC **H01L 21/28008** (2013.01); **H01L 21/84** (2013.01); **H01L 27/1203** (2013.01); **H01L 29/78648** (2013.01)

(58) **Field of Classification Search**

CPC H01L 29/78648
See application file for complete search history.

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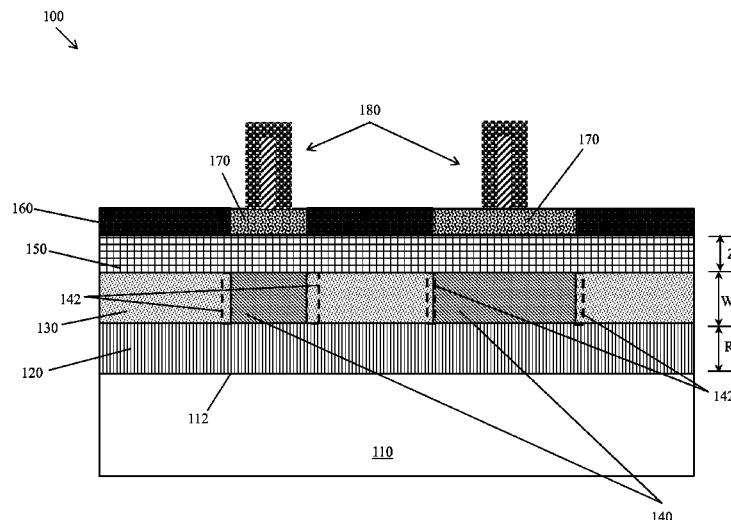
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(57) **ABSTRACT**

A method of forming a semiconductor device is disclosed. The method includes forming a first dielectric layer on a substrate; forming a set of bias lines on the first dielectric layer; covering the set of bias lines with a second dielectric layer; forming a semiconductor layer on the second dielectric layer; and forming a set of devices on the semiconductor layer above the set of bias lines.

19 Claims, 11 Drawing Sheets



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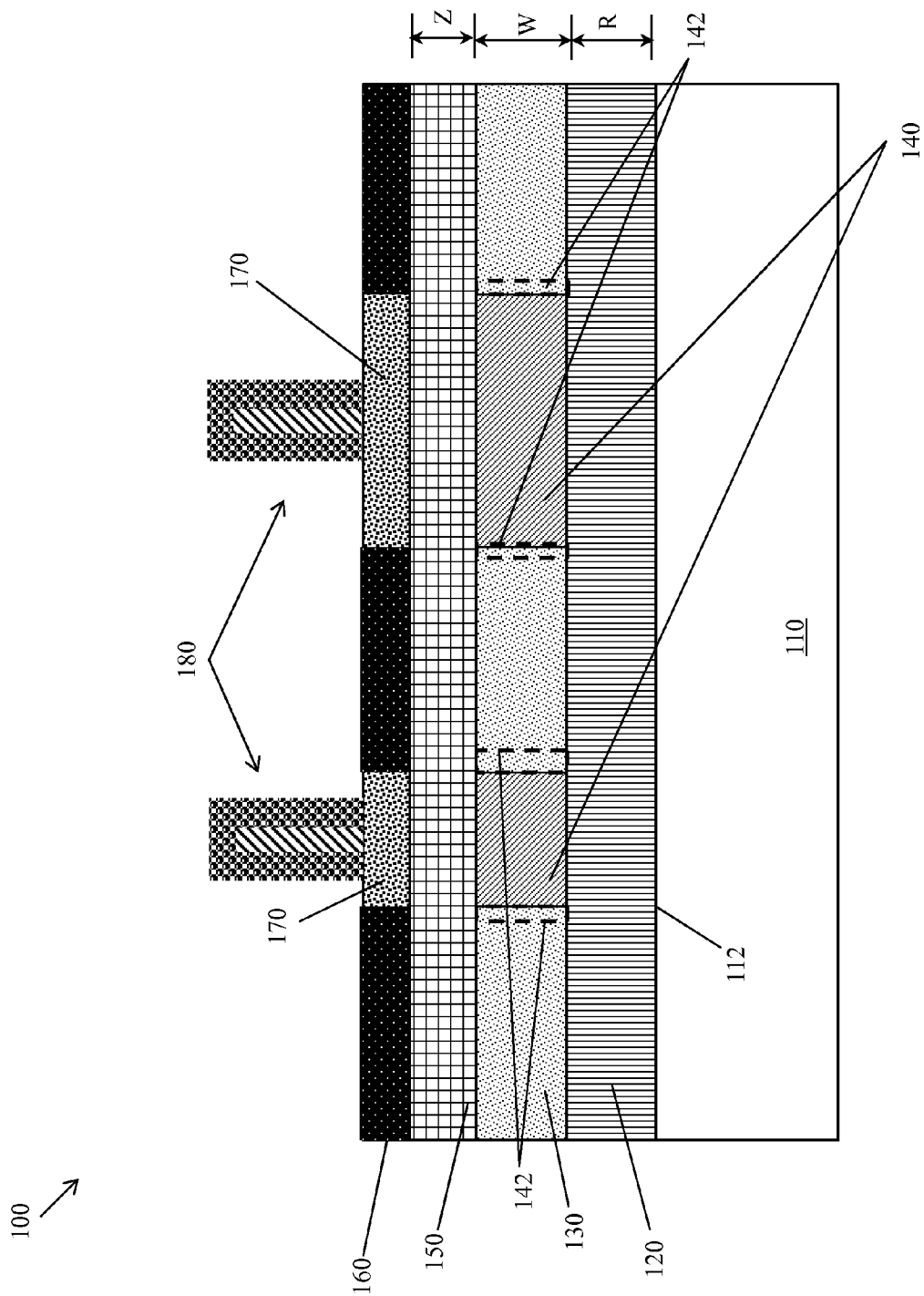


FIG. 1

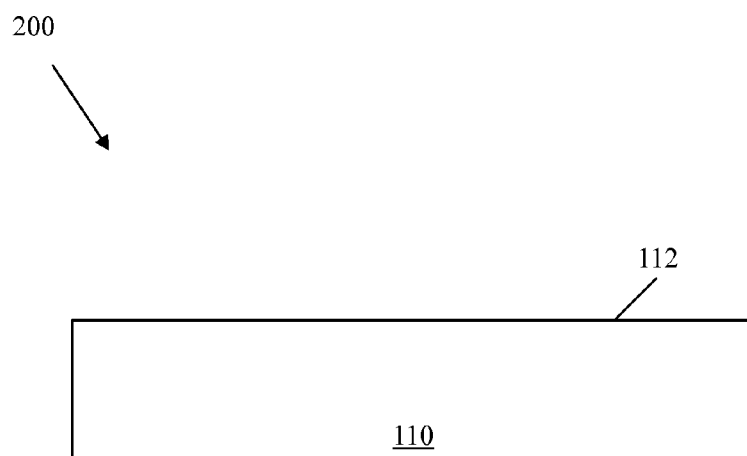


FIG. 2

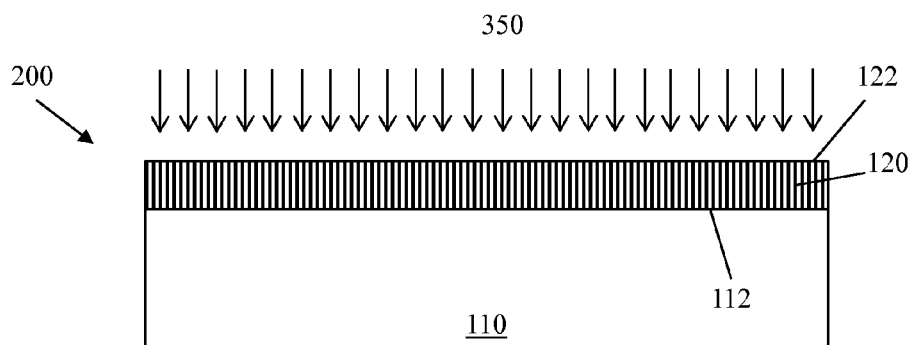


FIG. 3

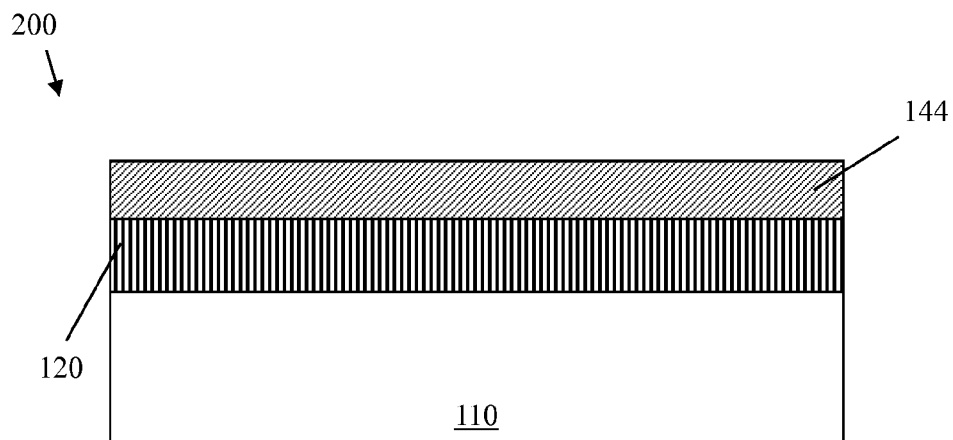


FIG. 4

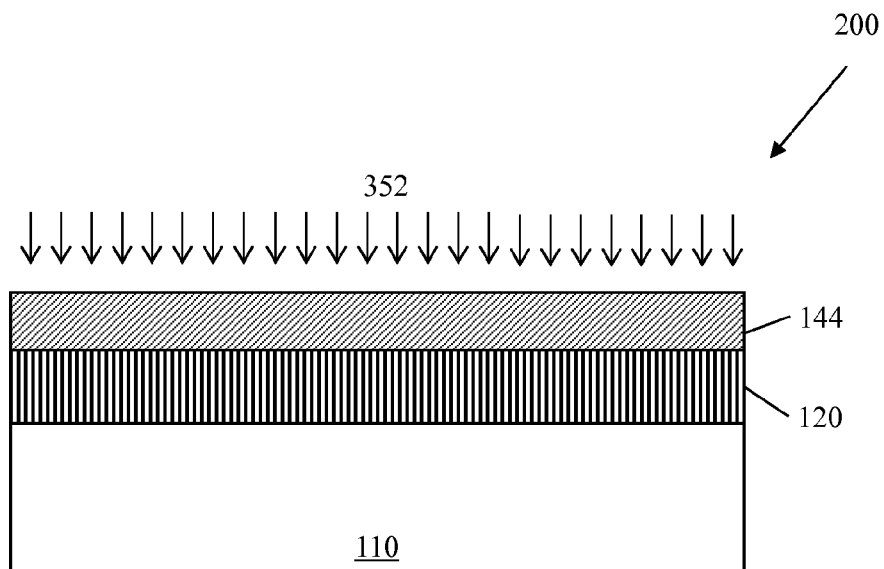


FIG. 5

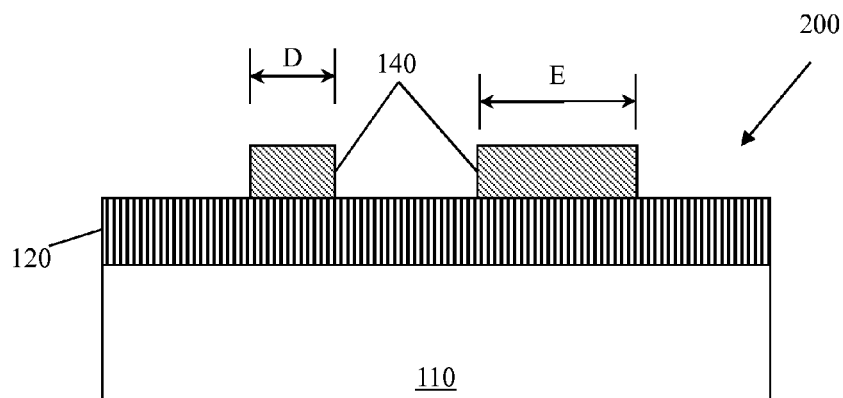


FIG. 6

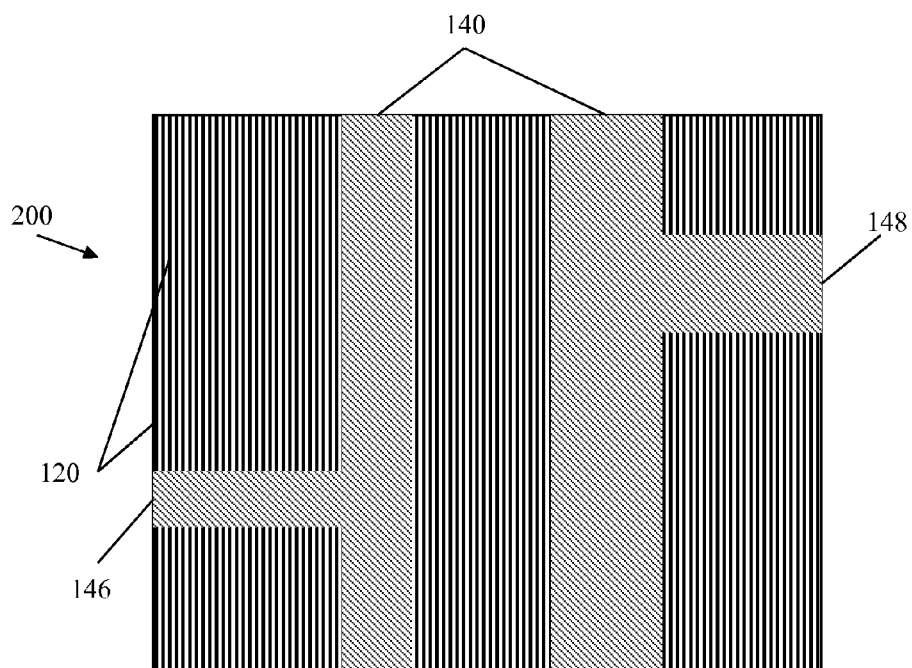


FIG. 7

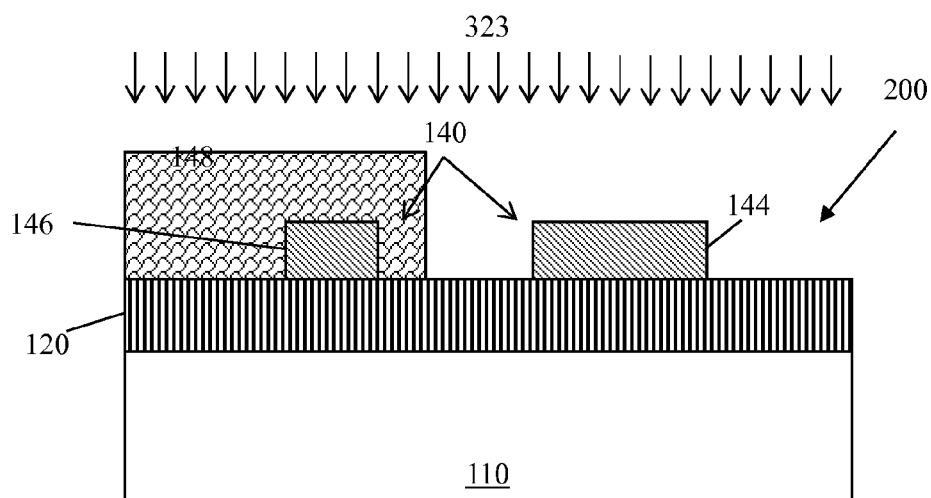


FIG. 8

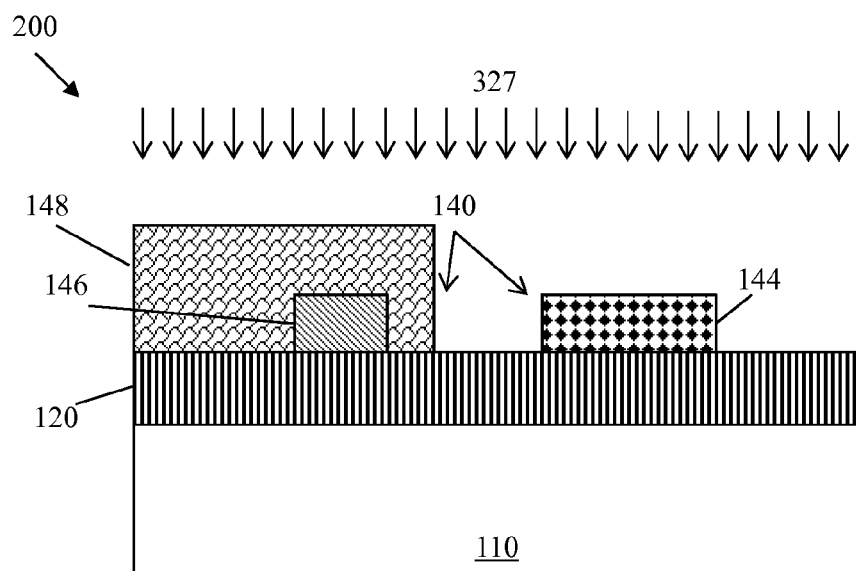


FIG. 9

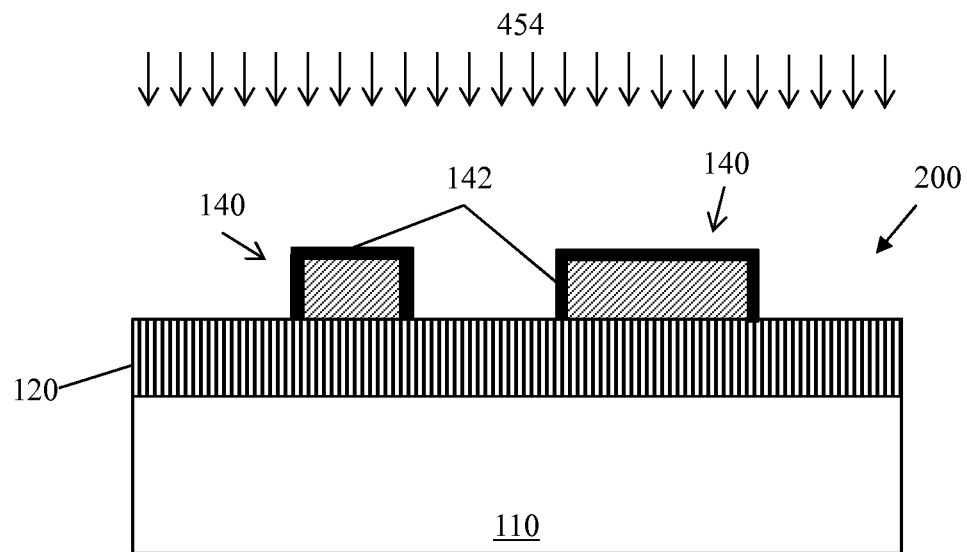


FIG. 10

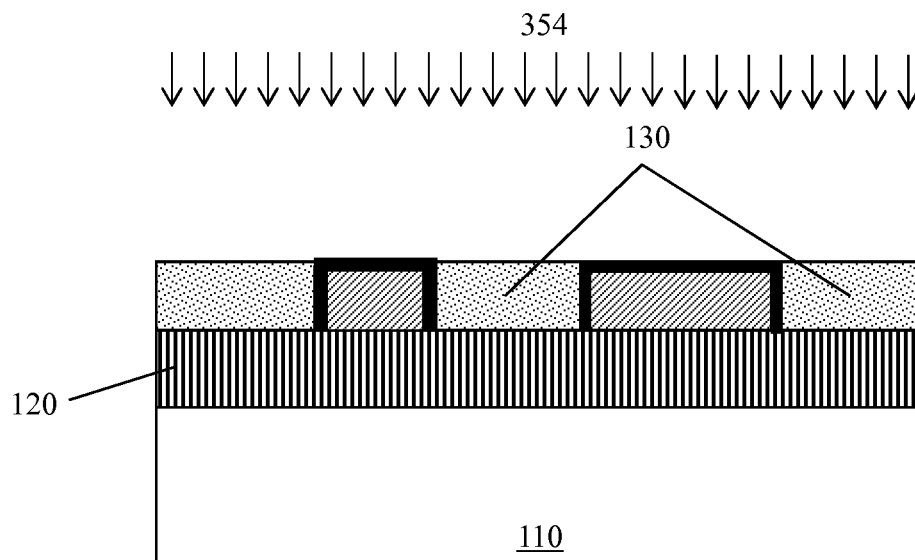


FIG. 11

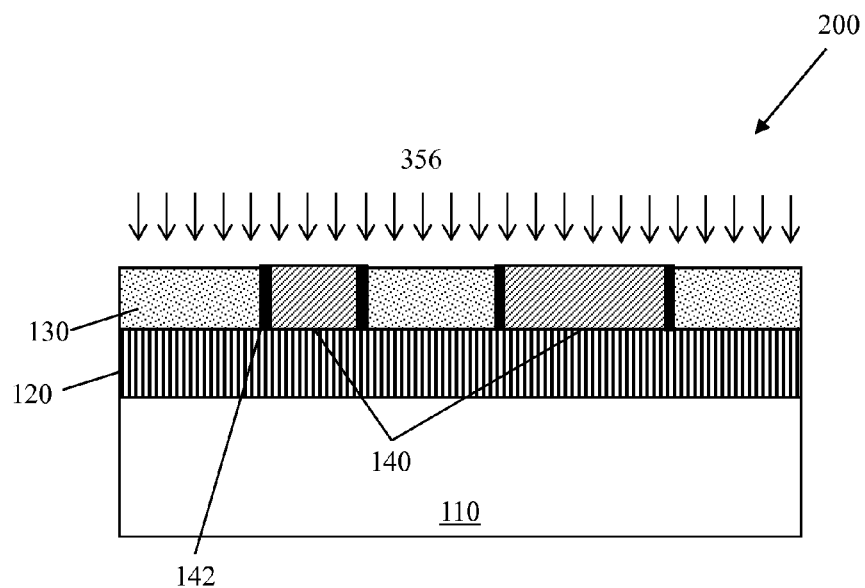


FIG. 12

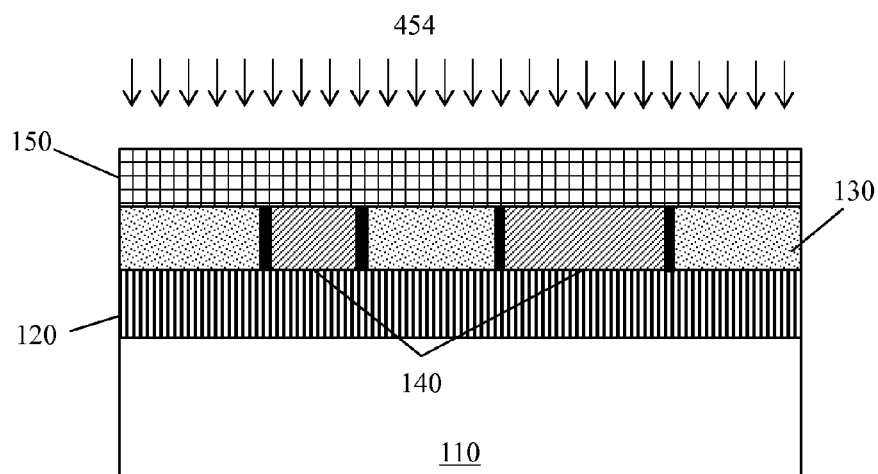


FIG. 13

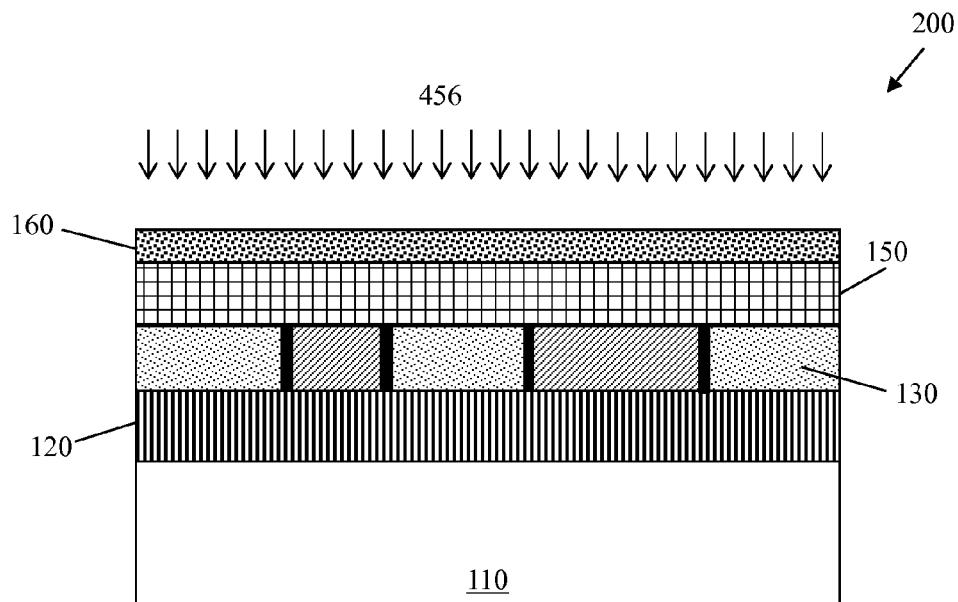


FIG. 14

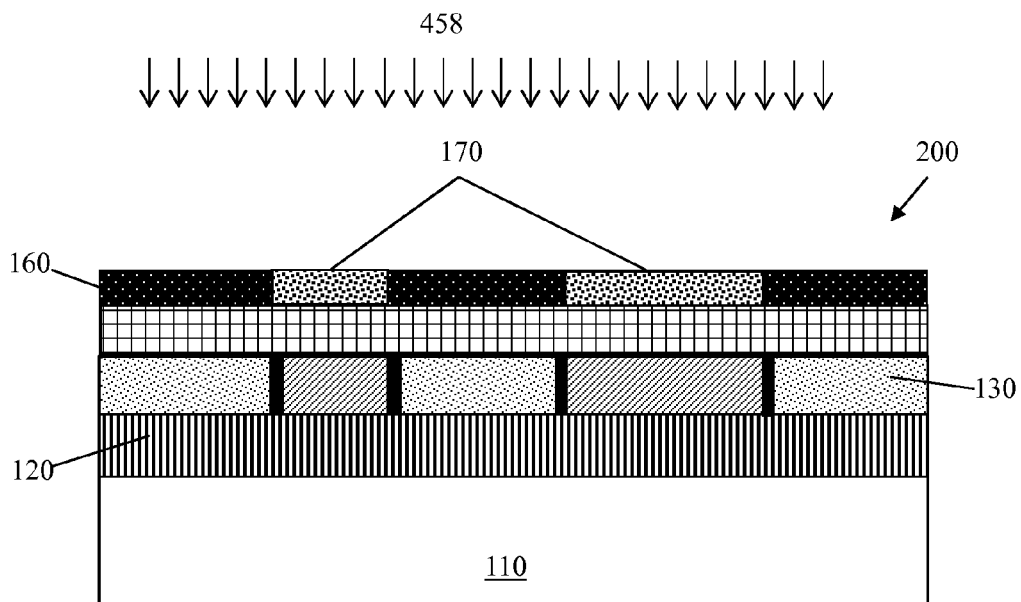


FIG. 15

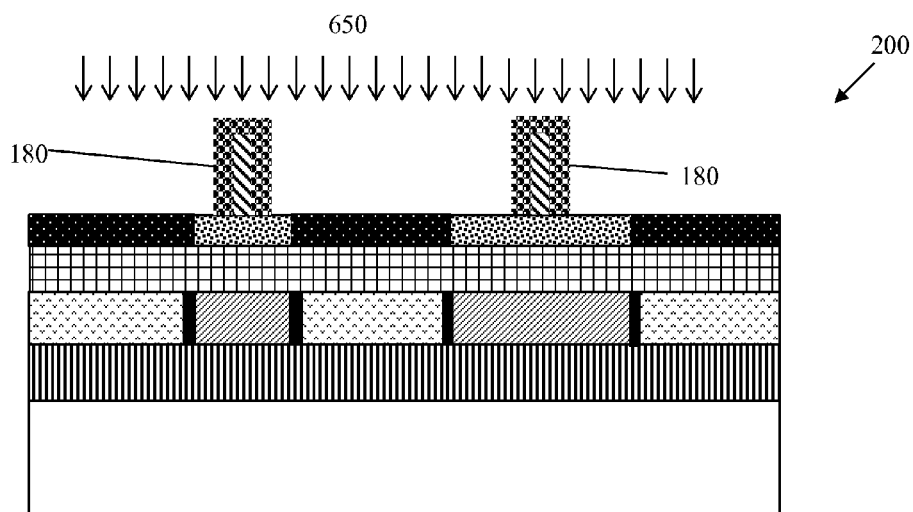


FIG. 16

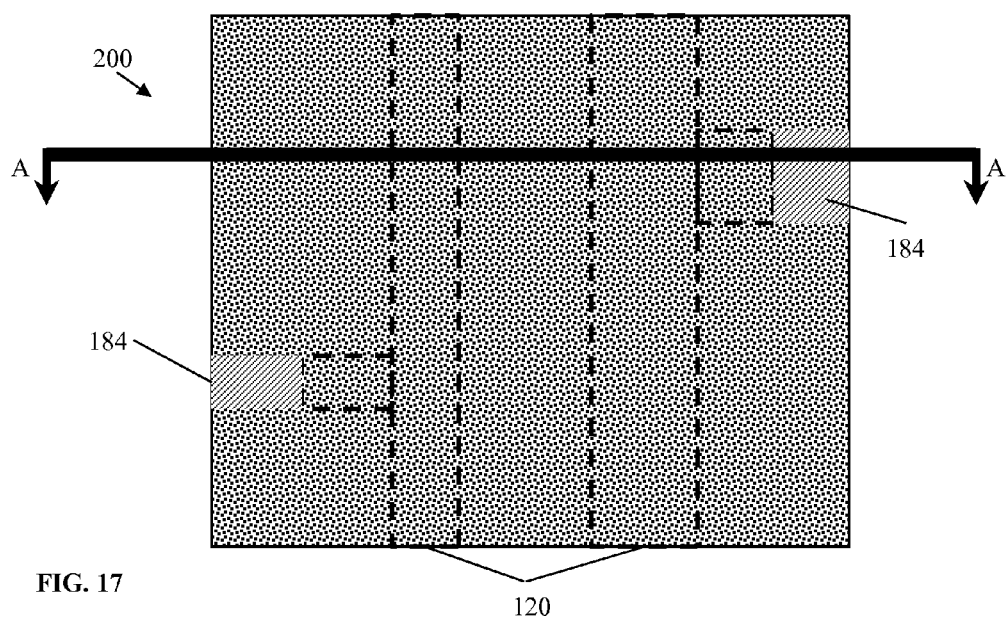


FIG. 17

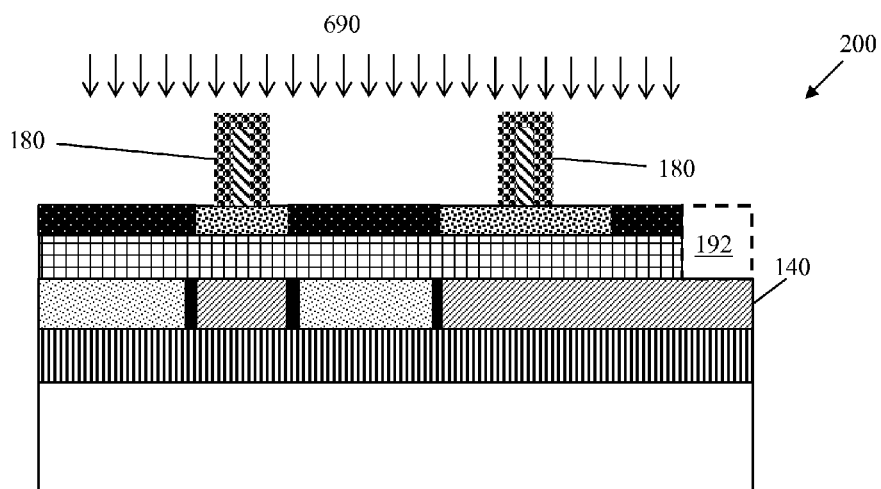


FIG. 18

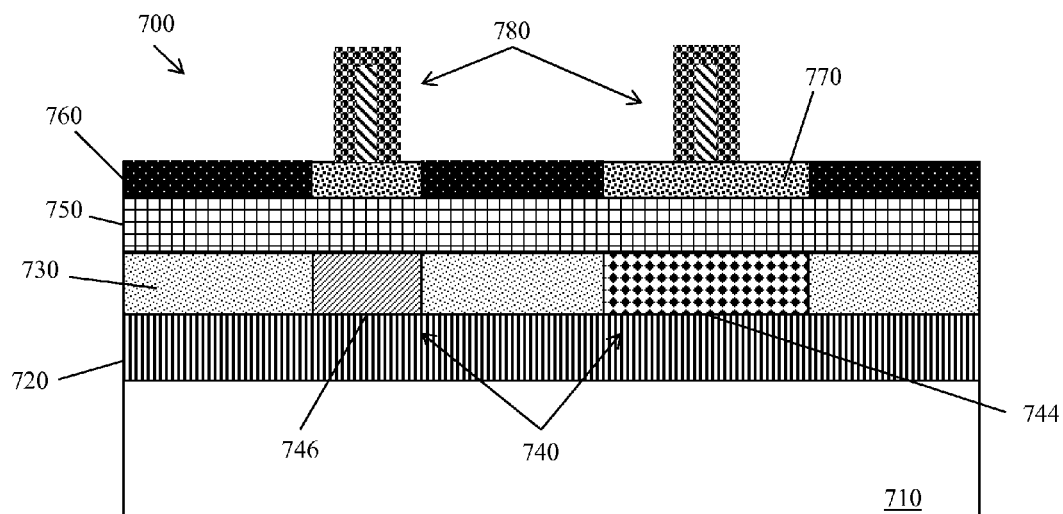


FIG. 19

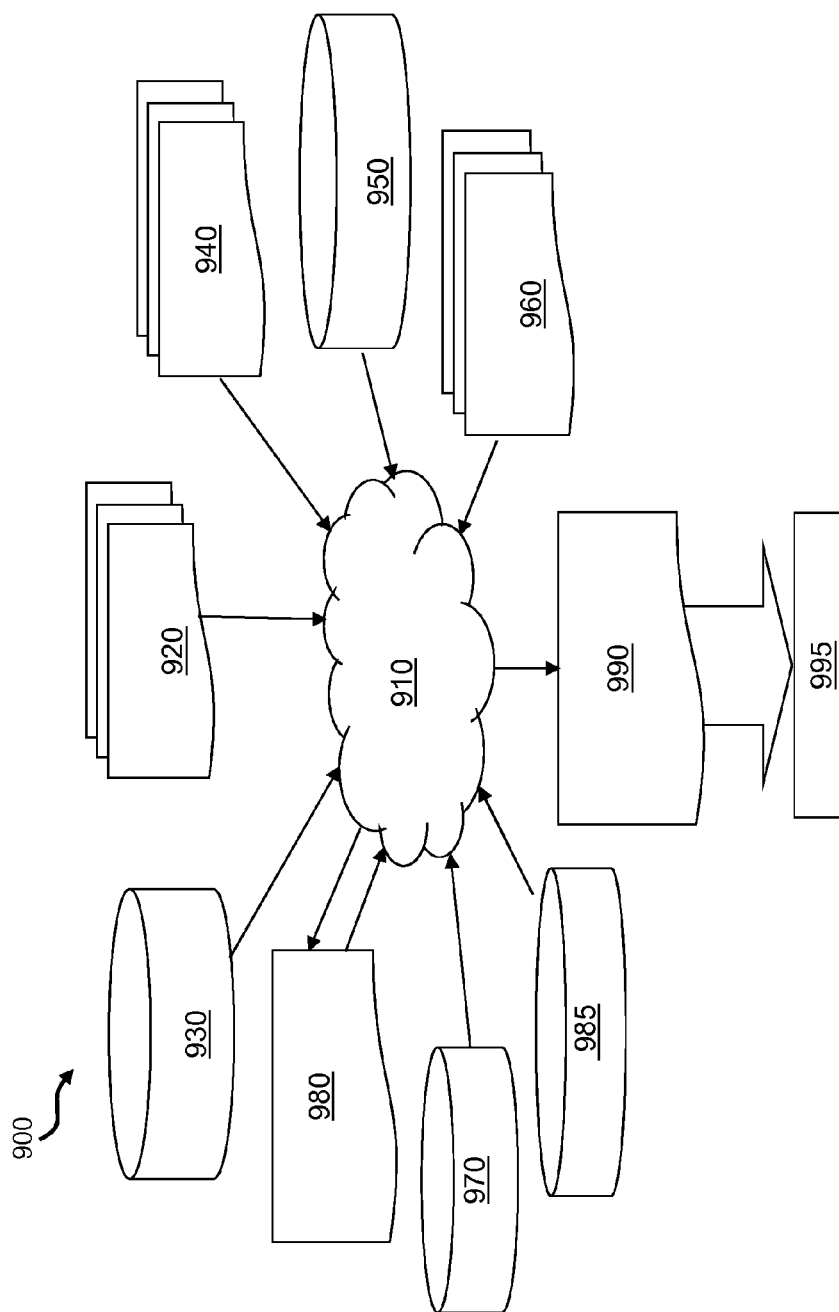


FIG. 20

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METHOD OF FABRICATING A SEMICONDUCTOR DEVICE INCLUDING EMBEDDED CRYSTALLINE BACK-GATE BIAS PLANES

FIELD OF THE INVENTION

Embodiments of this disclosure relate generally to semiconductor devices and, more particularly, to back-gate bias lines/planes in semiconductor device design, layout, and related methods of fabrication.

BACKGROUND

In the fabrication of integrated circuit (IC) devices (also referred to as semiconductor devices), many processes, steps, and techniques may be applied to form components and materials into the desired products. For example, in the fabrication of extremely thin silicon-on-insulator (ETSOI) devices, back-gate biases may be desired to tune device characteristics, manage power consumption, etc. Fabrication of these devices typically includes application of back-gate biases across a buried oxide (BOX) layer. However, in order to make the application of this back-gate bias across thick BOX layers effective, a large back bias voltage is required. Typically, the large back bias voltage is not practical with modern low operating voltage chips. As a result, this application limitation may require the use of ultra-thin body BOX (UTBB) technologies during fabrication. The requiring of the UTBB technologies during fabrication may increase cost, as well as increase design and process complexity.

BRIEF SUMMARY

A first aspect of the disclosure provides a method of forming a semiconductor device, the method including: forming a first dielectric layer on a substrate; forming a set of bias lines on the first dielectric layer; covering the set of bias lines with a second dielectric layer; forming a semiconductor layer on the second dielectric layer; and forming a set of devices on the semiconductor layer above the set of bias lines.

A second aspect of the disclosure provides a method of forming a backgate substrate, the method including: forming a first dielectric layer on a substrate, wherein the first dielectric layer includes a rare earth oxide (REO); forming a set of bias lines on the first dielectric layer, the set of bias lines including a first bias line with a first back-gate bias and a second bias line with a second back-gate bias; covering the set of bias line with a second dielectric layer; forming a third dielectric layer on the second dielectric layer; forming a semiconductor layer on the third dielectric layer; and forming a set of devices on the semiconductor layer above the set of bias lines, the set of devices including a first transistor disposed above the first bias line and a second transistor disposed above the second bias line.

A third aspect of the disclosure provides a semiconductor device including: a first dielectric layer disposed on a substrate; a set of bias lines disposed on the first dielectric layer; a second dielectric layer disposed on the first dielectric layer and between the set of bias lines; a patterned semiconductor layer disposed on portions of the second dielectric layer; and a set of devices disposed on the patterned semiconductor layer above the set of bias lines.

These and other aspects, advantages and salient features of the invention will become apparent from the following detailed description, which, when taken in conjunction with the annexed drawings, where like parts are designated by like

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reference characters throughout the drawings, disclose embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other aspects, features and advantages of the invention will be better understood by reading the following more particular description of the invention in conjunction with the accompanying drawings.

FIG. 1 is an illustration of a portion of a semiconductor device.

FIGS. 2-18 are illustrations of a method of forming a semiconductor device according to embodiments of the invention.

FIG. 19 is an illustration of a portion of a semiconductor device.

FIG. 20 is an illustration of a flow diagram of a design process used in semiconductor design, manufacture, and/or test according to embodiments of the invention.

It is noted that the drawings of the disclosure are not necessarily to scale. The drawings are intended to depict only typical aspects of the disclosure, and therefore should not be considered as limiting the scope of the disclosure. It is understood that elements similarly numbered between the FIGURES may be substantially similar as described with reference to one another. Further, in embodiments shown and described with reference to FIGS. 1-20, like numbering may represent like elements. Redundant explanation of these elements has been omitted for clarity. Finally, it is understood that the components of FIGS. 1-20 and their accompanying descriptions may be applied to any embodiment described herein.

DETAILED DESCRIPTION

FIG. 1 is an illustration of a cross sectional view of a portion of a semiconductor device 100 including a set of pre-patterned bias lines 140 shown according to embodiments. In an embodiment, semiconductor device 100 may include a substrate 110 with a first crystalline dielectric layer 120 (e.g., a crystalline oxide layer, a backgate dielectric layer, an epitaxially grown crystalline oxide layer, a rare earth oxide layer, etc.) disposed on a substrate surface 112 of substrate 110. In an embodiment, first layer 120 may be deposited on substrate surface 112 (e.g., a top surface) of substrate 110 and may have a thickness 'R' of about 10 nanometers to about 500 nanometers. In one embodiment, first layer 120 may have a thickness 'R' of about 10 nanometers to about 100 nanometers. Semiconductor device 100 may further include a second crystalline dielectric layer 130 disposed on first layer 120 and between a set of back-gate bias lines 140. Second layer 130 may have a thickness 'W' of about 5 nanometers to about 500 nanometers. In one embodiment, second layer 130 may have a thickness 'W' of about 10 nanometers to about 30 nanometers. Set of back-gate bias lines 140 may be disposed within second layer 130 and may include silicon, a highly doped silicon layer, an epitaxially grown silicon layer, and/or any semiconductor material which may be deposited on first layer 120 (e.g., an epitaxial oxide). In an embodiment, a set of thermal oxide liners 142 (shown in phantom) may be disposed between set of back gate bias lines 140 and second layer 130. A third crystalline dielectric layer 150 may be disposed on second layer 130 and set of back-gate bias lines 140. In an embodiment, third layer 150 may have a thickness 'Z' of about 5 nanometers to about 500 nanometers. In one embodiment, third layer 150 may have a thickness 'Z' of

about 10 nanometers to about 30 nanometers. Layers **120**, **130**, and **150** may include the same or differing materials and compositions.

As shown in FIG. 1, a semiconductor layer **170** (e.g., silicon) may be disposed substantially above and/or substantially aligned with set of back-gate bias lines **140** on third layer **150** and between a set of shallow trench isolations (STI) **160**. A set of devices (e.g., gates, transistors, field effect transistors (FET), etc.) **180** may be disposed on semiconductor layer **170** above set of back-gate bias lines **140**. In an embodiment, layers **120**, **130**, and **150** may allow for back-gate bias control. That is, layers **120**, **130**, and **150** may allow for maintaining the lattice information between underlying substrate **110** and layers and/or devices formed thereon.

Substrate **110** may be made from any known semiconductor materials including but not limited to, for example, silicon, germanium, silicon-germanium alloy, silicon carbide, and compound (e.g. III-V and II-VI) semiconductor materials. Non-limiting examples of compound semiconductor materials include gallium arsenide, indium arsenide, and indium phosphide. Typically substrate **110** may be about, but is not limited to, several hundred microns thickness. For example, substrate **110** may include a thickness ranging from about 0.5 mm to about 1.5 mm. In some embodiments, substrate **110** may consist essentially of one or more Group III-V compound semiconductors having a composition defined by the formula $Al_{X1}Ga_{X2}In_{X3}As_{Y1}P_{Y2}N_{Y3}Sb_{Y4}$, where $X1$, $X2$, $X3$, $Y1$, $Y2$, $Y3$, and $Y4$ represent relative proportions, each greater than or equal to zero and $X1+X2+X3+Y1+Y2+Y3+Y4=1$ (1 being the total relative mole quantity). Substrate **110** may also be comprised of Group II-VI compound semiconductors having a composition $Zn_{A1}Cd_{A2}Se_{B1}Te_{B2}$, where $A1$, $A2$, $B1$, and $B2$ are relative proportions each greater than or equal to zero and $A1+A2+B1+B2=1$ (1 being a total mole quantity). The processes to provide substrate **110**, as illustrated and described, are well known in the art and thus, no further description is necessary. It is understood that while examples described herein and in the figures are directed toward silicon semiconductor devices, these structures and/or material compositions are merely exemplary, and that the structures and processes described herein may be applied to any semiconductor device or material composition now known or later developed.

In an embodiment, at least one of first layer **120** or second layer **130** may be formed by epitaxial growth. Second layer **130** may be formed by epitaxial growth on top of first layer **120** (e.g., an epitaxial oxide layer, an REO layer, etc.). Layers **120**, **130**, and/or **150** (e.g., crystalline oxides, back-gate dielectric layers, etc.) may be formed of an epitaxial oxide grown on below layers of semiconductor device **100** and may include a rare earth oxide (e.g., cerium oxide (CeO_2), lanthanum oxide (La_2O_3), yttrium oxide (Y_2O_3), gadolinium oxide (Gd_2O_3), europium oxide (Eu_2O_3), terbium oxide (Tb_2O_3)). In one embodiment, layers **120**, **130**, and/or **150** may include combinations of rare earth oxides (e.g., a material such as ABO_3 , where 'A' and 'B' may be any rare earth metal (e.g., lanthanum scandium oxide ($LaScO_3$)). In one embodiment, layers **120**, **130**, and/or **150**, may include Perovskites (e.g. strontium titanate ($SrTiO_3$) or barium titanate ($BaTiO_3$)). In yet another embodiment, layers **120**, **130**, and/or **150**, may include aluminum oxide Al_2O_3 or aluminum oxide compounds (e.g., lanthanum aluminum $LaAlO_3$) which may be deposited by pulsed laser deposition (PLD). It is understood that the description of layers (e.g., crystalline dielectric layers) described herein are for illustrative purposes, and that any number, orientation, configuration, or combination of

crystalline dielectric layers may be used in accordance with embodiments of the invention.

In an embodiment, semiconductor layer **170** may be undoped and may be formed by epitaxial growth on top of third layer **150**. Besides silicon, other semiconductor materials such as germanium, silicon germanium, GeSn, III-V compound semiconductor, II-VI compound semiconductor materials may also be included in semiconductor layer **170**. In an embodiment, semiconductor layer **170** may be doped or undoped and may include: silicon, germanium, silicon-germanium alloy, and/or carbon doped silicon (Si:C). In one embodiment, semiconductor layer **170** may include carbon doped silicon with an atomic carbon concentration of between about 0.2 to about 4.0% substitutional carbon. In one embodiment, semiconductor layer **170** may include a carbon doped silicon type material having a concentration of about 0.3 to about 2.5% substitutional Carbon. It is understood that the total amount of carbon in semiconductor layer **170** may be higher than the substitutional amount. In a preferred exemplary embodiment, semiconductor layer **170** may include silicon, germanium, silicon germanium, carbon doped silicon, a silicon-germanium alloy, and compound (e.g. III-V and II-VI) semiconductor materials etc. In an embodiment, carbon doped silicon may include a concentration of substitutional Carbon (C) of about 0.4 to about 2.5%. Si:C.

FIGS. 2-18 are illustrations of a device undergoing a method according to embodiments of the invention. Although FIGS. 2-18 show the method of forming a portion of a semiconductor device **100** shown in FIGS. 1 and 18, it is understood that a similar method may be employed to form any other like semiconductor device.

Turning to FIG. 2, an illustration of a cross sectional view of a portion of a semiconductor device **200** including a substrate **110** is shown according to embodiments. In this embodiment, substrate **110** includes a substrate surface **112** for deposition and/or formation of regions, devices, and/or layers as described herein. The processes to provide substrate **110**, as illustrated and described, are well known in the art and thus, no further description is necessary.

Turning to FIG. 3, an illustration of a cross sectional view of a portion of semiconductor device **200** is shown undergoing formation **350** of first layer **120** on substrate **110** according to embodiments. In an embodiment, formation **350** may include epitaxial growth of first layer **120** (e.g., an epitaxial oxide) on surface **112** of substrate **110**. First layer **120** may be crystalline and may include a rare earth oxide (REO) as described herein. First layer **120** may be formed directly on substrate surface **112** of substrate **110** and may define a first oxide surface **122** located substantially opposite and/or parallel relative to substrate surface **112**. First layer **120** may be formed as a buried oxide (BOX) layer (e.g., an oxide layer disposed between semiconductor layers) as shown/described in embodiments herein. In one embodiment, substrate **110** may be subjected to an epitaxial growth process on substrate surface **112** to form first layer **120** on substrate **110** (e.g., first layer **120** may be epitaxially grown). In one embodiment, REO in first layer **120** may substantially cover substrate surface **112**, maintaining the lattice information between underlying substrate **110** and layers and/or devices formed thereon. It is understood that embodiments that are described herein with reference to specific substrates, regions, and layer orientations/compositions are for exemplary purposes, and that any combination of layers (e.g., oxide and nitride layers and configurations), implants, substrate modifications and/or trench placements may be included as an embodiment of the invention. The implants, regions, trenches, and/or layers described herein may be formed in substrates and/or layers

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which are substantially similar and/or different to those described and shown in FIGS. 1-18.

Turning to FIG. 4, an illustration of a device layer 144 (e.g., silicon) being disposed on first layer 120 is shown according to embodiments. Device layer 144 may be deposited and/or grown on first layer 120 and may include highly doped silicon. In an embodiment, device layer 144 may include materials consistent with set of back-gate bias lines 140 (shown in FIG. 1). Next, in FIG. 5, an illustration of device layer 144 being subjected to a forming process 352 (e.g., pattern and etch, etc.) to form/shape set of back-gate bias lines 140 (e.g., silicon lines) is shown in accordance with embodiments. Process 352 may selectively remove/etch portions of device layer 144 to first layer 120, forming/shaping set of back-gate bias lines 140. In one embodiment, process 352 may include a common mask and etch process as is known.

As can be seen in FIGS. 6 and 7, forming process 352 may form any number, shape, and/or configuration of set of back-gate bias lines on first layer 120. In FIG. 6, an illustration of a cross-sectional view of semiconductor device 200 following process 352 is shown according to embodiments. In an embodiment, process 352 may form device layer 144 (shown in FIGS. 4-5) into a set of back-gate bias lines 140 which may include varied dimensions 'D' and 'E' relative to one another. Further, in FIG. 7, an illustration of top view of semiconductor device 100 following process 352 is shown according to embodiments. As can be seen, back-gate bias lines 140 may be formed in any shape including a first contact region 146 and a second contact region 148 which may extend laterally across a surface of first layer 120/semiconductor device 200.

Turning to FIG. 8, semiconductor device 200 is shown being subjected to an optional masking process 323 according to embodiments of the invention. Masking process 323 may form a mask 148 on a first bias line 146 in set of back-gate bias lines 140 and not on a second bias line 144. Mask 148 may be formed in accordance with known mask and etch techniques and may cover portions of first bias line 146 and first layer 120 and expose portions of second bias line 144. Following formation of mask 148, as shown in the illustration of FIG. 9, a set of modification processes 327 may be performed on semiconductor device 200 in accordance with embodiments of the invention. In an embodiment, set of modification processes 327 may change/alter a material characteristic of exposed second bias line 144. In one embodiment, set of modification processes 327 may include doping (e.g., n-type doping, p-type doping, etc.) of second bias line 144. In another embodiment, set of modification processes 327 may include substitution (e.g., removal and replacement) of portions/materials of second bias line 144. In an embodiment, first bias line 146 and/or second bias line 144 may each be altered by masking process 323 and a set of modification processes 327 such that a material composition of first bias line 146 and second bias line 144 is different relative to one another, thereby producing a semiconductor device with varied bias line characteristics as shown in FIG. 19 and described further herein.

Turning to FIG. 10, an illustration of set of back-gate bias lines 140 being subjected to an optional oxidation process 454 (e.g., a thin thermal oxidation) for formation of a thin oxide layer 142 (e.g., a thermal oxide layer, an amorphous silicon oxide layer, etc.) around the set of back-gate bias lines 140 is shown according to embodiments. Next, in FIG. 11, an illustration of a formation process 354 covering the set of back-gate bias lines 140 with second layer 130 is shown according to embodiments of the invention. Formation process 354 may be non-selective or selective, and may form second layer 130 substantially between set of back-gate bias

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lines 140. In one embodiment, formation process 354 may include selective epitaxial growth of an epitaxial oxide on first layer 120. In another embodiment, formation process 354 may include non-selective epitaxial growth of an epitaxial oxide on first layer 120 followed by a chemical mechanical polishing. Second layer 130 and first layer 120 may include substantially similar or substantially varied material compositions. In one embodiment, first layer 120 and second layer 130 may include the same material.

Turning to FIG. 12, an illustration of semiconductor device 200 being subjected to an optional removal process 356 (e.g., a hydro-fluoric wet etch, a dry etch, etc.) to remove thin oxide layer 142 (e.g., thin oxide layer 142 on a top surface of set of back-gate bias lines 140) is shown according to embodiments. Removal process 356 may remove exposed portions of thin oxide layer 142 (e.g., top portions not bounded by second layer 130). It is understood that addition and removal of portions of thin oxide layer 142 are illustrative and optional, and that other embodiments of the invention as shown in FIGS. 1 and 19 may be formed without these steps/inclusion of these optional spacers.

Turning to FIG. 13, an illustration of a third formation 454 of a third layer 150 on top of second layer 130 and set of back-gate bias lines 140 is shown according to embodiments of the invention. Third layer 150 may substantially cover second layer 130 and set of back-gate bias lines 140. In an embodiment, third layer 150 may be strained or not strained depending on a condition of first and second crystalline dielectric layers 120 and 130 (e.g., the lattice engineering of the REO in first and second crystalline dielectric layers 120 and 130). Third layer 150, second layer 130, and/or first layer 120 may include substantially similar or substantially varied material compositions.

Turning to FIG. 14, an illustration of a semiconductor layer 170 (e.g., silicon) being disposed on third layer 150 is shown according to embodiments of the invention. Semiconductor layer 170 may be deposited and/or grown on third layer 150 and may include silicon. In an embodiment, semiconductor layer 170 may include materials consistent with set of back-gate bias lines 140. Next, in FIG. 15, an illustration of semiconductor layer 170 being subjected to a patterning process 458 (e.g., a shallow trench isolation process, etc.) to form/shape a set of STIs 160 is shown in accordance with embodiments of the invention. Process 458 may form/shape/locate set of STIs 160 between portions of semiconductor layer 170.

Turning to FIG. 16, an illustration of semiconductor device 200 being subjected to a set of formation processes 650 which may form a set of devices 180 (e.g., transistors, field effect transistors, etc.) on portions of semiconductor layer 170 proximate to set of STIs 160 is shown according to embodiments. Once formation of set of STIs 160 has stopped, a series of device formation processes 650 (e.g., FET formation) may develop devices on semiconductor device 200.

Turning to FIGS. 17-18, embodiments of portions of a wafer and semiconductor device 200 are shown in accordance with embodiments of the disclosure. FIG. 17 shows a top view of portions of semiconductor device 200. FIG. 18 shows a cross-sectional view of portions of semiconductor device 200 along line A-A in FIG. 17.

Referring to FIG. 17, an illustration of a top view of semiconductor device 200 being subjected to an opening process 690 (shown in FIG. 18) to access a set of contacts 184 of set of back-gate bias lines 140 following set of formation processes 650 is shown according to embodiments of the invention. In an embodiment, an etch may be performed through portions of semiconductor layer 160, set of STIs 160 and/or portions of third layer 150 to access/contact/connect to back-

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gate bias lines **140** (shown in phantom) through a set of contacts **184**. As can be seen in the cross-sectional illustration of FIG. **18**, opening process **690** creates an aperture/notch **192** (shown in phantom) through STI **160** and third dielectric layer **150**. Aperture **192** allows for direct access/connection to a back-gate bias line **140**.

Turning to FIG. **19**, an illustration of a cross sectional view of an alternative embodiment of a semiconductor device **700** including a set of back-gate bias lines **740** is shown according to embodiments. Semiconductor device **700** includes a substrate **710** with a first crystalline dielectric layer **720** disposed on a surface thereof. A second crystalline dielectric layer **730** is disposed on first layer **720**, beneath a third crystalline dielectric layer **750**, and between set of back-gate bias lines **740**. A semiconductor layer **770** and a set of STIs **760** may be formed on third layer **750** and a set of devices **780** may be formed on semiconductor layer **770** over set of back-gate bias lines **740**. In an embodiment, set of back-gate bias lines **740** may include a first back-gate bias line **742** which includes a first material (e.g., silicon germanium, silicon, carbon doped silicon, p-type, n-type, etc.), and a second back-gate bias line **744** which includes a second material (e.g., silicon germanium, silicon, carbon doped silicon, p-type, n-type, etc.) which is different from the first material. In one embodiment, first back-gate bias line **742** may be p-doped and second back-gate bias line **744** may be n-doped.

FIG. **20** shows an illustration of a flow diagram of an exemplary design flow **900** used for example, in semiconductor IC logic design, simulation, test, layout, and manufacture. Design flow **900** includes processes, machines and/or mechanisms for processing design structures or devices to generate logically or otherwise functionally equivalent representations of the design structures and/or devices described above and shown in FIG. **1**. The design structures processed and/or generated by design flow **900** may be encoded on machine-readable transmission or storage media to include data and/or instructions that when executed or otherwise processed on a data processing system generate a logically, graphically, structurally, mechanically, or otherwise functionally equivalent representation of hardware components, circuits, devices, or systems. Machines include, but are not limited to, any machine used in an IC design process, such as designing, manufacturing, or simulating a circuit, component, device, or system. For example, machines may include: lithography machines, machines and/or equipment for generating masks (e.g. e-beam writers), computers or equipment for simulating design structures, any apparatus used in the manufacturing or test process, or any machines for programming functionally equivalent representations of the design structures into any medium (e.g. a machine for programming a programmable gate array).

Design flow **900** may vary depending on the type of representation being designed. For example, a design flow **900** for building an application specific IC (ASIC) may differ from a design flow **900** for designing a standard component or from a design flow **900** for instantiating the design into a programmable array, for example a programmable gate array (PGA) or a field programmable gate array (FPGA).

FIG. **20** illustrates multiple such design structures (e.g., textual representations, graphical representations, data structural representations, etc.) including an input design structure **920** that is preferably processed by a design process **910**. Design structure **920** may be a logical simulation design structure generated and processed by design process **910** to produce a logically equivalent functional representation of a hardware device, and may include a text or a graphical representation. Design structure **920** may include at least one of

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a textual representation, a graphical representation, and a data structural representation of an integrated circuit and/or components thereof. Design structure **920** may also or alternatively comprise data and/or program instructions that when processed by design process **910**, generate a functional representation of the physical structure of a hardware device. Whether representing functional and/or structural design features, design structure **920** may be generated using electronic computer-aided design (ECAD) such as implemented by a core developer/designer. When encoded on a machine-readable data transmission, gate array, or storage medium, design structure **920** may be accessed and processed by one or more hardware and/or software modules within design process **910** to simulate or otherwise functionally represent an electronic component, circuit, electronic or logic module, apparatus, device, or system such as those shown in FIG. **1**. As such, design structure **920** may comprise files or other data structures including human and/or machine-readable source code, compiled structures, and computer-executable code structures that when processed by a design or simulation data processing system, functionally simulate or otherwise represent circuits or other levels of hardware logic design. Such data structures may include hardware-description language (HDL) design entities or other data structures conforming to and/or compatible with lower-level HDL design languages such as Verilog and VHDL, and/or higher level design languages such as C or C++.

Design process **910** preferably employs and incorporates hardware and/or software modules for synthesizing, translating, or otherwise processing a design/simulation functional equivalent of the components, circuits, devices, or logic structures shown in FIG. **1** to generate a netlist **980** which may contain design structures such as design structure **920**. Netlist **980** may comprise, for example, compiled or otherwise processed data structures representing a list of wires, discrete components, logic gates, control circuits, I/O devices, models, etc. that describes the connections to other elements and circuits in an integrated circuit or semiconductor design. Netlist **980** may be synthesized using an iterative process in which netlist **980** is resynthesized one or more times depending on design specifications and parameters for the device. As with other design structure types described herein, netlist **980** may be recorded on a machine-readable data storage medium or programmed into a programmable gate array. The medium may be a non-volatile storage medium such as a magnetic or optical disk drive, a programmable gate array, a compact flash, or other flash memory. Additionally, or in the alternative, the medium may be a system or cache memory, buffer space, or electrically or optically conductive devices and materials on which data packets may be transmitted and immediately stored via the Internet, or other networking suitable means.

Design process **910** may include hardware and software modules for processing a variety of input data structure types including netlist **980**. Such data structure types may reside, for example, within library elements **930** and include a set of commonly used elements, circuits, and devices, including models, layouts, and symbolic representations, for a given manufacturing technology (e.g., different technology nodes, 32 nm, 45 nm, 90 nm, etc.). The data structure types may further include design specifications **940**, characterization data **950**, verification data **960**, design rules **970**, and test data files **985** which may include input test patterns, output test results, and other testing information. Design process **910** may further include, for example, standard mechanical design processes such as stress analysis, thermal analysis, mechanical event simulation, process simulation for operations such as casting, molding, and die press forming, etc.

One of ordinary skill in the art of mechanical design can appreciate the extent of possible mechanical design tools and applications used in design process 910 without deviating from the scope and spirit of the invention. Design process 910 may also include modules for performing standard circuit design processes such as timing analysis, verification, design rule checking, place and route operations, etc.

Design process 910 employs and incorporates logic and physical design tools such as HDL compilers and simulation model build tools to process design structure 920 together with some or all of the depicted supporting data structures along with any additional mechanical design or data (if applicable), to generate a second design structure 990. Design structure 990 resides on a storage medium or programmable gate array in a data format used for the exchange of data of mechanical devices and structures (e.g. information stored in a IGES, DXF, Parasolid XT, JT, DRG, or any other suitable format for storing or rendering such mechanical design structures). Similar to design structure 920, design structure 990 preferably comprises one or more files, data structures, or other computer-encoded data or instructions that reside on transmission or data storage media and that when processed by an ECAD system generate a logically or otherwise functionally equivalent form of one or more of the embodiments of the invention shown in FIG. 1. In one embodiment, design structure 990 may comprise a compiled, executable HDL simulation model that functionally simulates the devices shown in FIG. 1.

Design structure 990 may also employ a data format used for the exchange of layout data of integrated circuits and/or symbolic data format (e.g. information stored in a GDSII (GDS2), GL1, OASIS, map files, or any other suitable format for storing such design data structures). Design structure 990 may comprise information such as, for example, symbolic data, map files, test data files, design content files, manufacturing data, layout parameters, wires, levels of metal, vias, shapes, data for routing through the manufacturing line, and any other data required by a manufacturer or other designer/developer to produce a device or structure as described above and shown in FIG. 1. Design structure 990 may then proceed to a stage 995 where, for example, design structure 990: proceeds to tape-out, is released to manufacturing, is released to a mask house, is sent to another design house, is sent back to the customer, etc.

The circuit as described above is part of the design for an integrated circuit chip. The chip design is created in a graphical computer programming language, and stored in a computer storage medium (such as a disk, tape, physical hard drive, or virtual hard drive such as in a storage access network). If the designer does not fabricate chips or the photolithographic masks used to fabricate chips, the designer transmits the resulting design by physical means (e.g., by providing a copy of the storage medium storing the design) or electronically (e.g., through the Internet) to such entities, directly or indirectly. The stored design is then converted into the appropriate format (e.g., GDSII) for the fabrication of photolithographic masks, which typically include multiple copies of the chip design in question that are to be formed on a wafer. The photolithographic masks are utilized to define areas of the wafer (and/or the layers thereon) to be etched or otherwise processed.

The method as described above is used in the fabrication of integrated circuit chips. The resulting integrated circuit chips can be distributed by the fabricator in raw wafer form (that is, as a single wafer that has multiple unpackaged chips), as a bare die, or in a packaged form. In the latter case the chip is mounted in a single chip package (such as a plastic carrier,

with leads that are affixed to a motherboard or other higher level carrier) or in a multichip package (such as a ceramic carrier that has either or both surface interconnections or buried interconnections). In any case the chip is then integrated with other chips, discrete circuit elements, and/or other signal processing devices as part of either (a) an intermediate product, such as a motherboard, or (b) an end product. The end product can be any product that includes integrated circuit chips, ranging from toys and other low-end applications to advanced computer products having a display, a keyboard or other input device, and a central processor.

While various embodiments are described herein, it will be appreciated from the specification that various combinations of elements, variations or improvements therein may be made by those skilled in the art, and are within the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A method of forming a semiconductor device, the method comprising:

- forming a first dielectric layer on a substrate;
- forming a set of bias lines on the first dielectric layer;
- covering the set of bias lines with a second dielectric layer after the forming of the first dielectric layer on the substrate;
- epitaxially growing a third dielectric layer on each of the second dielectric layer and the set of bias lines;
- forming a semiconductor layer on the third dielectric layer after the covering of the set of bias lines with the second dielectric layer; and
- forming a set of devices on the semiconductor layer above the set of bias lines.

2. The method of claim 1, wherein at least one of the first dielectric layer or the second dielectric layer includes an epitaxial oxide.

3. The method of claim 1, wherein the first dielectric layer, the second dielectric layer, and the set of bias lines are is epitaxially grown.

4. The method of claim 3, wherein the epitaxial growth of the set of bias lines and the first, second, and third dielectric layers transfers lattice information from the substrate to the semiconductor layer.

- 5. The method of claim 1, further comprising:
 - performing a thermal oxidation to the set of bias lines following the forming of the set of bias lines to form a thin oxide layer between the set of bias lines; and
 - removing portions of the thin oxide layer on a top surface of the set of bias lines.

6. The method of claim 1, wherein the forming of the semiconductor layer comprises epitaxially growing the semiconductor layer on the second dielectric layer.

7. The method of claim 1, further comprising forming a device layer on the first dielectric layer, wherein at least one of the device layer or the semiconductor layer includes silicon.

8. The method of claim 1, wherein the set of bias lines include a first bias line which is p-type and a second bias line which is n-type.

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9. The method of claim 1, wherein at least one of the first dielectric layer or the second dielectric layer includes a rare earth oxide (REO).

10. The method of claim 1, wherein the set of bias lines include a first bias line which includes a first material and a second bias line which includes a second material which is different than the first material.

11. The method of claim 1, wherein a thickness of each of the second dielectric layer and the third dielectric layer is between approximately five nanometers and approximately thirty nanometers.

12. A method of forming a semiconductor device, the method comprising:

forming a first dielectric layer on a substrate,

wherein the first dielectric layer includes a rare earth oxide (REO);

forming a set of bias lines on the first dielectric layer, the set of bias lines including a first bias line with a first back-gate bias and a second bias line with a second back-gate bias;

covering the set of bias line with a second dielectric layer after the forming of the first dielectric layer on the substrate;

epitaxially growing a third dielectric layer on each of the second dielectric layer and the set of bias lines;

forming a semiconductor layer on the third dielectric layer after the covering of the set of bias lines with the second dielectric layer; and

forming a set of devices on the semiconductor layer above the set of bias lines, the set of devices including a first

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transistor disposed above the first bias line and a second transistor disposed above the second bias line.

13. The method of claim 12, wherein at least one of the second dielectric layer or the third dielectric layer includes an epitaxially grown.

14. The method of claim 12, wherein the first dielectric layer, the second dielectric layer, and the set of bias lines are epitaxially grown.

15. The method of claim 14, wherein the epitaxial growth of the set of bias lines and the first, second, and third dielectric layers transfers lattice information from the substrate to the semiconductor layer.

16. The method of claim 12, further comprising:

performing a thermal oxidation to the set of bias lines following the forming of the set of bias lines to form a thin oxide layer between the set of bias lines;

removing portions of the thin oxide layer on a top surface of the set of bias lines; and

forming the third dielectric layer on the second dielectric layer and the set of bias lines.

17. The method of claim 12, further comprising forming a device layer on the first dielectric layer, wherein the first back-gate bias and the second back-gate bias have a different value relative to one another and at least one of the device layer or the semiconductor layer includes silicon.

18. The method of claim 12, wherein the first bias line is p-doped and the second bias line is n-doped.

19. The method of claim 12, wherein the first bias line includes a first material and the second bias line includes a second material which is different than the first material.

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